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MAPS FOR COMMAND AND CONTROL: THE HUMAN FACTORS ISSUES,(U)
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(6) MAPS FOR COMMAND AND CONTROL: THE HUMAN FACTORS ISSUES

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ABSTRACT

Maps are an important source of information in all types of command and control and specialized maps for tasks in this area are desirable. However, fundamental human factors research is needed before such maps can be developed. This report reviews some of the human factors issues involved in the design and evaluation of maps as information display systems. It concludes that there are four main areas in which research should be applied: analysis of user requirements; categorization of map problem-solving tasks; techniques for coding information on computer-based map displays; and techniques for scaling computer-based maps.

INTRODUCTION

Maps are an important source of information in all types of command and control centers. Graphical representation of information on a map display assists the radar operator who is monitoring airspace from an air surveillance center, the intelligence team reconstructing a maritime reconnaissance patrol mission, and the battalion commander who is briefing his staff on offensive tactics. Since the map display often provides the focus for much of this command center activity, it is appropriate to consider some of the human factors issues involved in the design and evaluation of maps as information display systems.

Most maps used in the command and control environment are geographic outline maps with tactical symbology representing military units added as a transparent overlay, usually by hand. The map display must be updated as new tactical positions are established, requiring either that the current symbology be erased and relocated or else that a new overlay be fitted, and the entire tactical configuration be re-drawn. Although the map should ideally provide a succinct summary of the tactical situation by displaying information of various types integrated from several sources (e.g., equipment and weapons positions, weather or sea state, terrain information, mission planning data), this is not practical due to the manual updating procedures.

Different arms of the military have different requirements for map information. For example, terrain vegetation may be of great interest to an infantry officer who is planning the cross-country movements of a company of soldiers, but is probably of little use to the pilot flying low on a bombing mission. He, instead, is concerned with the positions of hydro towers and other potential obstructions along his flight path. Another consideration is the type of representation used to present the map data. For example, a three-dimensional representation of the underwater environment would be valuable for naval surveillance mission. There is a lack of maps supplying information for these varying military environments, and many military operations are carried out using civilian topographic maps whose information may not be relevant or complete.

Providing space for displaying paper maps is another problem faced by command and control centers, particularly in the field. The necessary environmental data is often only available on a large-scale map, yet the geographic scope of the military operation may be quite large. The combination results in an unwieldy map or series of maps, difficult to manipulate in confined quarters and requiring a large wall space or table top for display.

The solution to many of these problems seems to be the development of specialized maps for all command and control environments. Before such maps can be developed, however, many fundamental questions relating to how people read maps must be addressed.

Robinson and Petchenik (1976) define a map as a "graphic representation of human knowledge about the the environment". Usually this representation is visual, but it need not be; tactile maps have been created for use by blind people. Maps range in style and content from pictorial (for example, collages showing points of interest for tourists) to abstract (e.g., time-distance maps in which the physical configuration of a country corresponds to travel time, rather than distance). Most maps used in command and control tasks are symbolic maps, and this paper will refer mainly to that type of environmental representation.

Maps have advantages over verbal, numerical, or tabular information displays because they allow correlation of data in space. They provide an ordering or simplifying system which organizes and structures the physical elements represented on the map while at the same time, displays the spatial relationship between them. Furthermore, a well-designed map may often reveal structures or interrelationships that might otherwise remain hidden (Robinson and Petchenik,1976). It is the function of the map to engender a comprehension of the environment through the selection, presentation and emphasis of appropriate environmental features.

MAPS AS COMMUNICATION SYSTEMS

The process of mapping begins with the acquisition and selection of data about the environment by the cartographer and it ends with actions taken in that environment by the map user. Thus we can regard the map as a medium of communication between the cartographer and the map reader (Kolacny,1968). The objective of the cartographer is to communicate a set of ideas about the real world as effectively as possible to the reader (Brandes,1976). To do this, he extracts a set of information from the world, generalizes and abstracts it, and illustrates it by a symbolic representation, i.e., the map. The map reader then forms his own mental image of the real world, based on what he perceives on the map (Fig. 1). The measure of success of the communication is the accuracy with which the map reader mentally reconstructs the real world. The reader's view of reality is unlikely to correspond exactly to the cartographer's because of selection, omission and simplification of information and the encoding, decoding and transformation of information at various stages in the mapping process.

Maps can also act as a medium of communication between two or more users, each of whom may have his own mental image of the environment. In this situation, the map provides a starting point and a focus for the discussion by giving a succinct representation to which reference can be made and annotation added.

THE MAP USER

Maps should be designed to present the particular information that the user needs to carry out his task. Yet efforts by cartographers to determine the user's requirements have been surprisingly few, restricted mainly to specialized military applications such as projected map displays (McGrath,1972) or maps for low altitude, high speed flight (Taylor and Hopkin,1975). In these latter cases, the user requirements can be assessed with some success because the task is well defined. Also, the user population tends to be fairly uniform in terms of experience and skill. Objective techniques for determining the requirements of other more general groups of map users have not been developed, leading to a heavy dependence on the user questionnaire, with its attendant problems of design and interpretation. In some cases, the map users themselves do not know what they need. From a survey designed to establish the requirements of a relatively informed group of map users in Britain, Kirby (1970) concludes that "most are not sufficiently knowledgeable to offer developed opinions on the finer points of representation and scale". Moreover, studies have indicated that user preferences are often poor predictors of eventual map performance (Wheaton et al.,1976). Research is needed which includes or excludes map information in a systematic fashion, and then evaluates the effect of these changes on particular map utilization tasks.

The relevant characteristics of the general map-reading population are extremely variable and often unpredictable. Map reading ability will depend on the user's education, his general experience with maps, and his familiarity with the environment being portrayed. It will also depend on the less quantifiable psychological factors of motivation and expectation. There is no "average map reader". It is almost impossible to construct a single map, even for a very specific task, which will suit all users. The cartographer must inevitably compromise and produce a map which will be most intelligible to the highest percentage of users (Wood,1972).

The difficulties imposed on map design by such a wide range of users have lead many cartographers to call for improved education of map users (Wood, 1972). Some specu-

late that there may be particular inherent abilities in some people (e.g., spatial manipulation ability) that, if recognized and enhanced by training, would produce better map readers. Although some types of training have succeeded in improving map reading skill, particularly for well-defined tasks such as contour interpretation, studies have shown that in many cases more general map reading education has not been effective in improving map reading ability. Effective training programs are difficult to set up mainly because there is little basic information on how people comprehend maps (Brandes,1976). Recently, experimenters have begun to study the problem of training for map comprehension. In a series of map learning experiments, Thorndyke and Statz (1979) found large individual differences in subjects' ability to memorize fictional maps. Interestingly, these differences were not correlated with previous map-using experience, but were related to the use of certain strategies and learning procedures, particularly those used for encoding spatial information. When subjects were instructed in the use of the effective strategies prior to a map learning task in a subsequent experiment, map learning performance improved significantly.

CURRENT DESIGN PROBLEMS

A map can display only a subset of the total information available concerning the environment, and this subset is selected and manipulated by the cartographer. The process of information reduction by selection, omission and simplification which is used to produce the subset is called generalization (e.g., the representation of all cities with population under 10,000 by the same symbol). It has the effect of producing a smaller number of more extensive classifications of information. Opposite to generalization is the process of abstraction, where a large category is divided into several subcategories (e.g., division of urban centers into cities, towns and villages). This allows map features to be related through particular attributes and is one way of providing structure. It is the job of the cartographer to make judgements on the differences and similarities between objects in the environment to be mapped, and then to carry out the necessary generalizations and abstractions before the map can be constructed. Thus there can be many different maps of a given environment. Because different user tasks require different information, the generalizations and abstractions that may provide a suitable map structure for one task may not be appropriate for another.

Many maps are unsuccessful in transmitting all the data they contain because they are overcrowded. This is partly because map features are presented in a limited display area and their distribution is largely pre-determined.

Also, specialized maps are often too expensive to design and print, and so one general map must display the information required by many potential users and tasks. Taylor and Hopkin (1975) point to the high information content and complexity of topographic displays as the single underlying problem common to most map design issues. Although users often prefer detailed maps, a U.S. Army Research Institute study (Granda,1976) has shown that there were no significant differences between standard maps and reduced detail maps in map use performance, amount of information requested or time taken for particular map utilization tasks.

In many cases,a more stringent process of initial content selection would reduce the problem of clutter, but this requires a detailed knowledge of the exact task to be performed by the map reader. The alternative is to use more extensive and sophisticated methods of encoding the data, increasing both the number of dimensions and the number of steps within these dimensions. At some point the encoding becomes too complex and subtle, being no longer useable by the majority of map readers.

The use of standard symbols to represent the same information on different types of maps would reduce the size of the user's map "vocabulary", lessening confusion and easing the task of training. There have been several attempts in this direction by international cartographic associations, but except for particular applications (e.g., civil aviation) these efforts have not been successful. Brandes (1976) and others consider proposals for standardization premature until it is determined which symbol is most effective in communicating a particular cartographic meaning.

HUMAN FACTORS RESEARCH ON MAPS

Coding Techniques

Very little work has been done on the way people read and comprehend maps to create a mental image of the environment. The techniques used in map-reading differ from other information-gathering tasks, such as reading, because the map viewer can start looking at any point on the map and has no fixed, sequential scanning pattern for obtaining information as he does in reading. Acquiring knowledge from a map depends on processes for focussing attention, encoding information and integrating various types of knowledge (Thorndyke and Statz, 1979).

Early human factors work in cartography investigated the perception of individual map symbols. Flannery (1956) found that when circles of graduated area are used to represent values, map readers consistently underestimate the

quantity represented. The relation between perceived symbol size and actual symbol size was described by a mathematical function. Other researchers (Crawford, 1973; Miehoefer 1973) have since determined the appropriate functions for several different symbols (e.g., squares, bars, wedges, and cubes). Cartographers have also been concerned with the discriminability of dot shading patterns used for marking area on maps (Williams, 1958; Jenks and Knos, 1961; Castner and Robinson, 1969). The perceptual effect of these patterns depends on the complex interaction of dot form, size, spacing and arrangement, and the influence of these factors is not yet fully understood.

The high information content of maps makes it essential to employ efficient ways of coding map features. Although there is a large body of human factors data on visual coding, it is not immediately obvious whether these recommendations apply to maps, with their complex interrelationships of symbols. For example,although a number of human factors literature reviews have suggested that shape coding should be pictorial rather than abstract (because this facilitates learning and memory), a pictorial symbol on a map display is not necessarily the shape most quickly located or easily discriminated (Potash,1977). The value of such a representation for a given application must be empirically determined. Generally, such recommendations have not been validated on maps, possibly because the research on map displays cannot be carried out on "simplified" map stimuli, representing limited portions of information normally found on maps, but requires the full map with all its attendant complexity (Potash, 1977).

Research on map coding should provide a measure of the relative efficiency of different coding schemes and a measure of discriminability between coding values for a given scheme. Williams (1971) used relative eye fixations (the ratio of the number of fixations on an item other than desired to the number of fixations on desired items) as a measure of discriminability between different coding methods (shape, size and colour) in a visual search task. He then used the same technique to look at the discriminability of different coding values within a given coding scheme (e.g., circle, triangle, and square within shape coding). His measure of coding efficiency is one of the few that have been developed, and can be easily applied to a variety of displays and types of search tasks.

The majority of studies on coding have been conducted using visual displays other than maps. The following summarizes the results of the few coding experiments which have used maps as the stimulus material.

Hitt (1961) compared five different abstract coding

methods (numeral, letter, geometric shape, colour and configuration) using five different types of operator tasks: identify, locate, compare, count and verify. He found that numeral coding and colour coding were best in general. The effects of selected combinations of target and background coding on map reading performance using the same tasks were investigated by Christner and Ray (1961) in another part of the same study. Three types of target coding (hue, numerals, shape) were combined with five types of background coding (colour, solid grey, white, patterned grey and different shades of grey). These were studied for different display complexities. (Total number of targets, number of coding levels for targets and clustering of targets were all varied). This study was one of few which attempted to discover the effects of interrelated map variables. It was found that background coding did not make a significant difference in time taken for tasks. Numeral coding was superior for the identify task and colour coding for the locate and count tasks. For the compare and verify tasks, no difference was found among the 15 target-background combinations.

Shontz et al. (1971) compared performance on a visual search task for colour-coded and uncoded checkpoint location on aeronautical charts. Here colour served as a partially redundant code. It was found that colour coding for information location is most effective when many categories of information must be coded, colours highly discriminable in peripheral vision are used and the number of objects per category is kept small (below 11).

Cuff (1971) has carried out some interesting cartographic investigations relating colour shading to temperature. He compared three colour schemes: dark red progressing to light red to light blue to dark blue; a range of red from dark to light; and a range of blue from dark to light. The latter two schemes were found preferable, with highest temperature matched with darkest colour. This work was extended to magnitude indication using similar shading schemes in a later experiment.

Although these studies constitute a start, much more research is required on map coding. One problem that has not been investigated is that of choosing an optimum coding scheme to depict a particular attribute of a map feature. For example, physical dimension may be best coded by a size coding system, but it is not clear what scheme best represents more abstract attributes such as value or availability.

Perceptual Organization

Work done in the fields of perceptual and cognitive psychology may offer some insights into the map reading pro-

cess. For example, Niesser's (1967) work on perception proposes that stimuli are processed in two stages: the first, the pre-attentive, is fast, crude, holistic and parallel in nature; the second, the focal stage, concentrates on detail, and is slower, more deliberate and sequential. These two levels of processing are very evident in map reading, where the viewer first has an awareness of the map as a whole, as a network of lines, areas and symbols, and then gradually zeroes in on a single limited portion of the field. The speed at which this latter activity takes place is dependant on the nature of the stimulus configuration and the visual differences (coding) in the field.

Several cartographers have endeavoured to apply some of the older psychological notions of figure and ground and the Gestalt laws of visual organization to map design (Wood, 1968, 1972). They claim that by manipulating the figure/ground to produce a visual hierarchy on a map, a sequence of visual processing is established that leads the map reader in an orderly fashion through the various marks on the map. Dent (1972) mentions several techniques that the cartographer can employ to facilitate figure formation on maps, such as variation of contrast through differences in texture (areal pattern) and brightness at the edge of a figure. However, these principles are still fairly intuitive, and generally suffer from a lack of solid scientific verification.

Memory for Maps

Much of the psychological research on maps as information systems has involved the memorization of maps. In one study, Shimron (1975) found that subjects took less time to learn local connections between cities and landmarks and more time to learn co-ordinate relationships between cities and to integrate the overall map information. He also found that when the map was presented as a series of "schemes", or overlays of one type of information on top of another, subjects had more difficulty integrating the map than when the map was built up in sections consisting of all the information in a given area. More research of this type is required, for a variety of map tasks besides memorization.

A current issue in cognitive psychology that is relevant to map design concerns the representation of information in memory, whether it is stored in some analogue and spatial way, or whether storage is based on linguistic structure. Several recent experiments (Pavio, 1975; Kosslyn, 1975) argue for a visual analogue representation. However, an experiment by Stevens and Coupe (1978) found that memory for spatial information (specifically, a simple map) can be structured in a linguistic hierarchy which can, in some cases, distort memory for the subordinate spatial

relationships. They claim that an image system can not satisfactorily account for their results. Thorndyke and Statz (1979) state that map elements have both spatial extent and a linguistic label. In their map-learning experiments, subjects' procedures for encoding information operated on either verbal (linguistic) information or on shape and location information. When individual differences between subject's performance were examined, it was found that all subjects learned the linguistic information equally well, but that there were differences in ability to learn the spatial. The work of Janssen and Michon (1973) on internal representation of networks (for example, mazes) is also relevant. In their experiments, subjects must develop a global image of the network, which is only presented in a segment-by-segment fashion. The authors hypothesize that complexity of the network, as measured by the number of crossings and number of corners, will influence accuracy of reproduction of the network.

Finally, considerable effort has been devoted to determining the mental models people have of a particular environment. These so-called cognitive maps have been studied by environmental psychologists such as Lynch (1960) and Downs and Stea (1973) who conclude that people code elements of the environment selectively, depending on their experience, and often have distorted notions of distance. Hooper (1979) emphasizes the importance of understanding these mental models because "the organizational schemes used by people in integrating environments will be reflected in their organization of map information".

COMPUTER-BASED MAP DISPLAYS

The field of cartography is turning increasingly to computers for solutions to problems of geographic data storage and for the design and printing of maps. Systems are being developed for digital collection of geographic data using satellites, for automated extraction of map symbology and contour information from source imagery (Stockman, 1978), for interactive creation and revision of maps from a digitized data base (Molloy, 1977) and for the automated plotting of the final cartographic product (Stutz, 1975).

A natural extension of digital storage of geographic data is its presentation directly to the map user on a computer display. Research on the design of these electronic maps has only recently begun, but already it seems that such systems offer many advantages over traditional paper maps. The basis for many of these advantages lies in the fact that the user is no longer dealing with a static, often outdated, paper display, but is interacting with a whole system for manipulating geographic data. This means that specialized

maps can easily be created to suit specific tasks. Information selection will be carried out either by the cartographer, or, ideally, by the map user himself, who will interactively select and delete various subsets of information according to the requirements of his task. Since the amount of data displayed on the electronic map at any time may be less than on a paper map, clutter can be minimized and the need for extensive data coding techniques may also be reduced. In fact, it will be possible to personalize maps by allowing the user to choose his own symbols and methods for geographic data coding for use at his own local terminal.

Electronic maps will also have the capability to provide the user with a wide selection of map scales and to switch easily between pre-set scales or to zoom in a continuous fashion from a small-scale overview of a geographic area to a large-scale detailed display of a selected portion of that area. Furthermore, electronic maps will permit the display of time-varying data, for example, time-compressed histories of military troop or vehicle movement. This capability to present information in a dynamic fashion may prove to be the great strength of the electronic map display.

The linkage of the user via the computerized map display to a data bank will allow him to access much more information than is normally available on a paper map. Since it is much easier to update a computer data bank than a paper map, the geographic data can also be more current. Detailed non-geographic and descriptive data on map features could be culled from this data bank and displayed either on the map itself or on an auxiliary alphanumeric display. A computer-based system will be able to perform many routine problem-solving tasks that the map reader must currently carry out. These tasks range from determining the grid location of a particular map feature, to calculating the optimal route between two points. A reallocation of map problem solving tasks will leave the map user with more time to concentrate on those geographic problems requiring his unique capabilities for recognition of patterns and trends.

Exploratory studies of experimental computer-based map display systems by researchers at the Advanced Research Projects Agency (Anderson and Shapiro, 1979) have concluded that "interactive map display systems should be considered a viable candidate for many command and control applications". However, they caution that because electronic maps will act as problem-solving aids, and not just displays, their design will necessarily be very different from current maps.

The implementation of computer-based map displays in command and control systems will not be possible until topographic (and tactical) data are available in a digitized

form. The U.S. Defence Mapping Agency has already started to compile such an environmental data base. The cartographic data system supporting a map display will demand huge computer storage capabilities and efficient methods of structuring and accessing data elements so that user response time is satisfactory. System reliability will be a primary concern in military systems used in the field. Many of these problems will be solved by a rapidly-growing computer technology. It is the man-computer interface that will present basic human factors problems that must be investigated now if the power of these systems is to be fully realized.

POTENTIAL RESEARCH AREAS

This review of the current state of map design suggests that there are four main areas to which research effort on map displays for command and control systems should be applied:

1. Analysis of user information requirements.
   There is a need for a thorough analysis of the information required by command and control personnel for display on a map. The issue can become complicated when the map is used in conjunction with other sources of information (e.g., as part of a computerized information retrieval system). The problem then becomes one of deciding what portion of the total information can profitably be displayed in graphic form on the map, and what part should be presented on a supplementary alphanumeric display. An evaluation of the effectiveness of the computerized map display in presenting time-varying data is particularly important.

2. Categorization of map tasks.
   Linked to the problem of analysing the user's information requirements is the need for a comprehensive breakdown of map problem-solving tasks. Anderson and Shapiro (1979) state that they "are not able to offer a definitive taxonomy of the uses of maps, even for the limited area of command and control". Hooper (1979) has started by grouping map tasks into four categories: symbol interpretation, matching a map with the environment, planning actions, and remembering maps, but this preliminary categorization must be extended. Such a categorization would be very useful for general evaluation of map displays and in particular, for comparison between displays when the final map task cannot be well defined. As computer assistance for geographic problem-solving becomes more common, a task ca-

tegorization will be essential for determining the allocation of tasks between man and machine.

3. Map coding.
Research into techniques for coding maps will continue to be important, especially for computerized map displays, where a different and more limited range of coding methods is used. Among the problems requiring investigation are the selection of symbols to represent map feature attributes, techniques for providing a map legend, and the possibility of having the map user define his own symbols and coding systems.

4. Map scale.
The capability to portray geographic information at different scales may be a very powerful feature of a computerized map display system. However, implementation of such a feature raises problems of perspective control and user orientation. Experimentation will be required to determine the size of the map "window" and the amount of information that should be displayed to the user at any scale. Research will also be necessary to determine the ratios of map scale that will prevent the user from becoming disoriented as he switches from one to another. The utility of continuous scaling ("zoom") should be compared to discrete scale levels. There will be a requirement to change symbol abstraction as map scale is interactively varied (e.g., cities which are represented by symbols such as circles on a small-scale map must, at some point, be drawn as occupying an area as the scale is enlarged). Techniques for handling these different levels of symbol abstraction must be developed.

CONCLUSIONS

Paper maps have hitherto been the source of topographic and strategic information in the command and control environment. Development of specialized maps for command and control is desirable, but should properly await fundamental research into the ways in which the human user perceives and integrates the information on a map. Problems of symbology, coding, clutter, the wide variety of map users and often the lack of knowledge of the user's task and information requirements, together with the technical difficulties of map production have conspired to limit the utility of the map display in command and control. Research in cartography has tended to concentrate on methods for geographic data collection, reduction and map printing.

Relatively little research has been carried out on the human factors issues in map design. With the application of computer technology to cartography, and the availability of digital geographic data bases, the computerized map display will become a new and powerful problem-solving tool for command and control personnel. However, it is essential that experimentation be carried out to resolve some basic design issues before such systems are implemented. Research on map display systems for command and control systems should concentrate on determining the user's information requirements, categorization of map problem-solving tasks, and studying map coding and scaling on computer displays.

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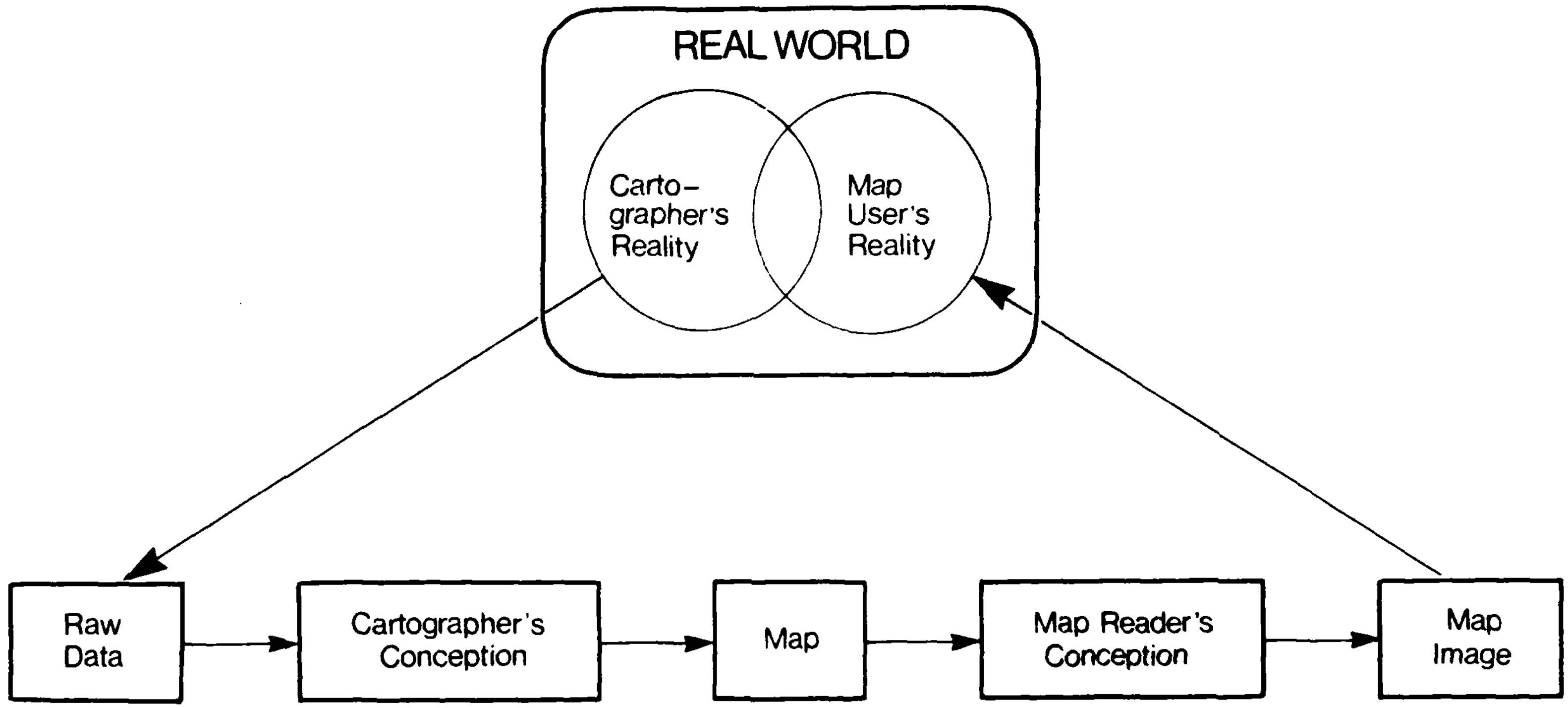

Cartographic Communication

FIGURE 1

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